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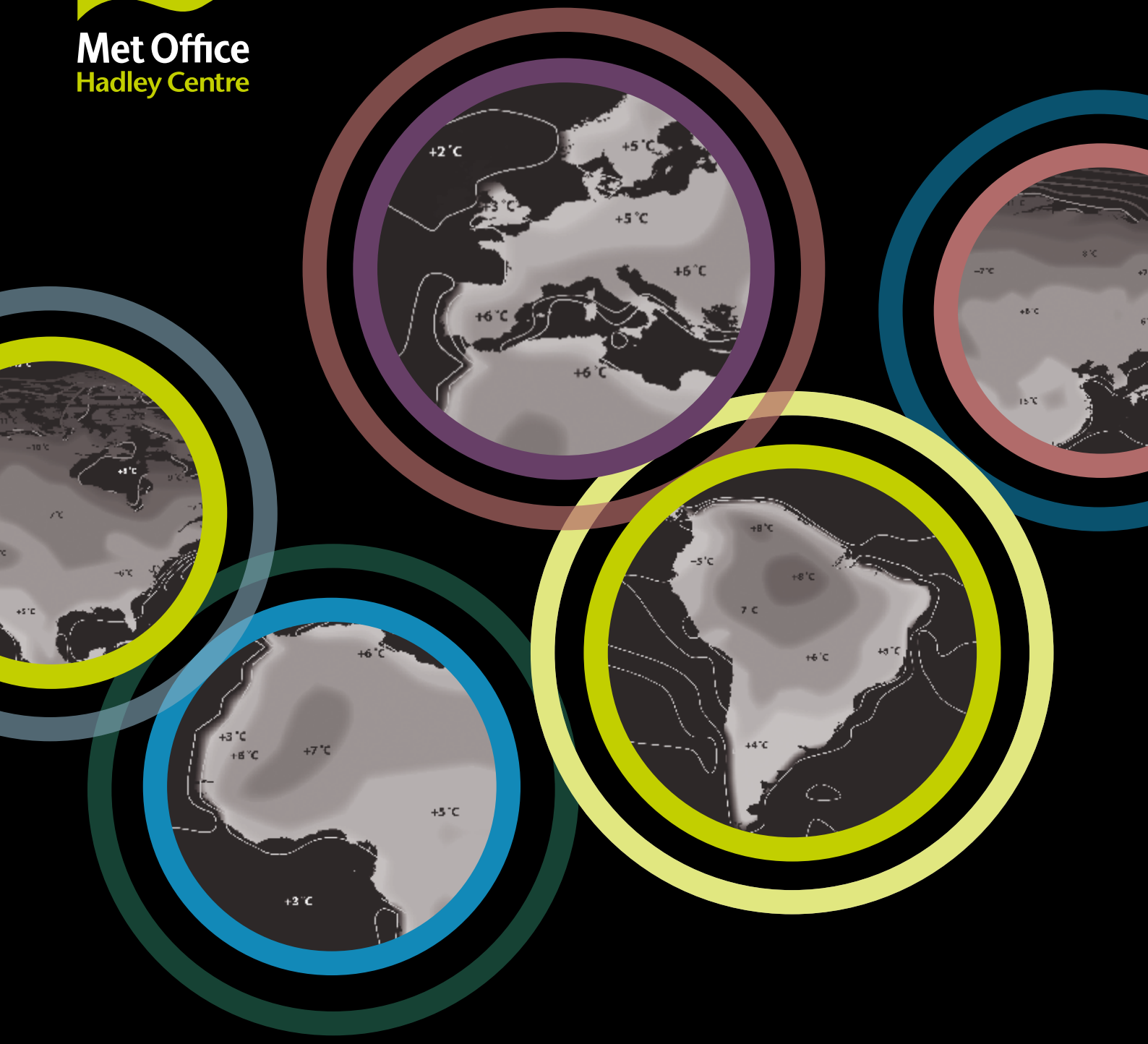

Science

Driving our response to climate change

Australian Government
Bureau of Meteorology

CSIRO

ECMWF

Environment Agency

NATURAL ENVIRONMENT RESEARCH COUNCIL

RESEARCH COUNCILS UK

UKaid
from the Department for International Development

UK Climate Impacts Programme

UNDP

Met Office working in partnership

Informing choices

Some climate change is inevitable and it's essential we begin to put adaptation strategies in place. Properly applied science and research will inform our choices in dealing with climate change around the world, supporting sustainable development and global equity.

The climate modelling tools and results from the Met Office Hadley Centre can help. Some of these have already been used by scientists and planners to build capacity and inform decisions, particularly in the UK and some developing countries.

Climate change will affect all aspects of life — increasing risks to food security, water availability, infrastructure and human health. Meeting the challenges requires the best possible information with predictions at global, regional and local levels, and on timescales from the coming month to a century ahead. This information needs to be interpreted to highlight the real impacts, and combined with specific advice to help everyone prepare for the future.

The Met Office, working with a growing number of partners, is pioneering the use of climate science to provide solutions for some of these issues. Here, we highlight recent projects and research which are breaking new ground in this developing area.

"[Climate research] is of crucial importance in informing so many people around the world of the nature of the threat, the huge challenges we all face."

Prince Charles, Speaking at the Met Office HQ, September 2009

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Tools for adaptation and sustainable development – 1

Seasonal forecasting and updating baseline climate

SEASONAL FORECASTING

Met Office seasonal North Atlantic tropical storm forecast

The North Atlantic tropical storm season is typically from June to November each year. The term 'tropical storm' includes tropical cyclones (average wind speeds of at least 39 mph) through to hurricanes (average wind speeds of at least 74 mph). The degree of activity varies greatly from season to season, both in terms of the number of storms and their combined strength and duration. These factors combined are measured by the Accumulated Cyclone Energy (ACE) index.

The year to year variability in the number of tropical storms forming over the North Atlantic is mainly influenced by variability in sea surface temperatures (SST) over both the tropical North Atlantic and the tropical Pacific. The El Niño Southern Oscillation (ENSO) is characterised by fluctuations in SST in the tropical Pacific, and predictions of how ENSO will behave are crucial to understanding how the hurricane season will unfold.

The Met Office produces a forecast at the start of each North Atlantic tropical storm season, giving an estimate of the most likely number of storms and ACE index. The climate model used represents important interactions between ocean and atmosphere including the influence of SST in generating storms. A number of forecasts are run, and the results are used to determine the most likely outcome.

	Number of tropical storms			ACE index		
	Best estimate	70% range	Observed	Best estimate	70% range	Observed
2009	**6**	**3–9**	--	**60**	**40–80**	--
2008	15	11–19	15	180	154–206	141
2007	9	6–13	12	81	61–102	71
2006	13	10–17	9	136	112–161	76
2005	18	8–29	25	174	114–235	239

Table. Best estimate and 70% range for forecasts of the number of tropical storms and ACE index for July–November 2005–2009.

The forecasts have demonstrated a considerable level of skill. For example, it indicated a particularly active season for 2005, which was the most active season on record with 25 storms and an ACE index of 239. It also picked up the sudden shift to the below-average season in 2006, which saw nine storms and an ACE index of 76. In 2008 the Met Office forecast for the most likely number of tropical storms was 15, exactly the number observed during the forecast period.

For 2009, the Met Office forecast a best estimate of six tropical storms from July to November, with a 70% chance that the number will be in the range three to nine. This represents below-average activity relative to the 1990–2005 long-term average of 12.4.

Hurricane Bill, 18 August 2009. NASA MODIS Rapid Response Team.

At the time the forecast was issued (June 2009) the Met Office seasonal prediction system was indicating that SSTs in the tropical east and central Pacific would warm and remain substantially warmer than average through to the end of the hurricane season (November). El Niño is known to be associated with below-average tropical storm activity in the North Atlantic. The developing El Niño, in conjunction with predicted cooler than average SSTs in the tropical North Atlantic, both contributed to the predicted below-average tropical storm activity.

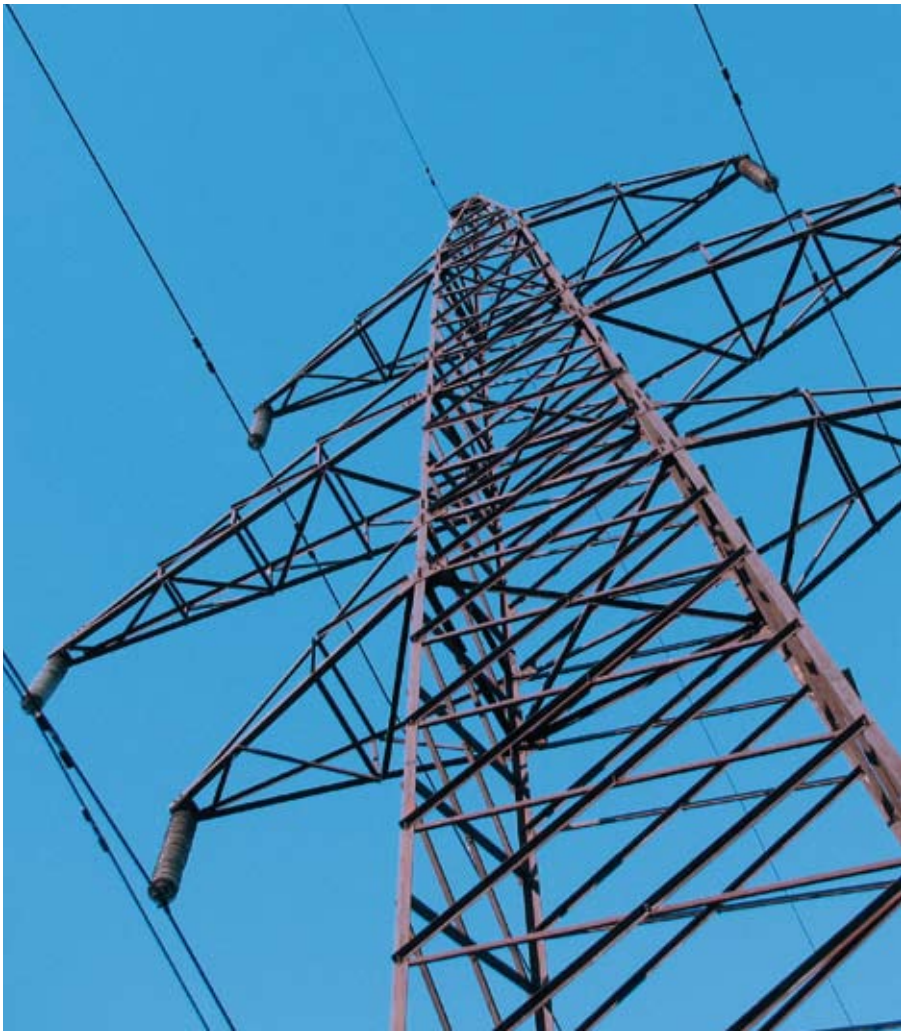
Late winter European climate response to El Niño

The ENSO in the tropical Pacific has wide-ranging effects on climate, not only in the Pacific region, but across the whole globe. For example, moderate El Niño events are linked to cold conditions in northern Europe and mild conditions in southern Europe during late winter. This response is large enough to be a potentially significant foundation for winter seasonal forecasts for Europe.

The Met Office has shown that this response can be realistically simulated in an atmospheric model which includes the upper layers of the atmosphere. In models without the upper layers the response is not seen. Enhanced representation of the stratosphere is now being incorporated into the Met Office seasonal prediction model. Of course, in any year the natural variability in our climate may be a complex combination of factors, of which El Niño is just one, but it's important that known links such as this are used wherever possible.

"Historical temperature climatologies are no longer valid because climate is not stationary. The new climatologies that take account of climate change are already being adopted and will improve demand forecasting and planning out to 10 years ahead."

Nick Roberts
EP2 Project Board Chairman



UPDATING BASELINE CLIMATE

Good quality climatological information can help public and private sector decision-makers understand their vulnerability to current weather and climate change. Historical long-term temperature averages are traditionally used as a baseline for planning over the next few years. However, our climate is already changing and the past is no longer a good guide for the future or even for present day climate.

A climatological 30 year period from 1971–2000 is typically used in the UK. Warming trends mean this is more representative of the 1980s than of present-day climate. Global mean land temperature has increased by about 0.5 ˚C since the mid 1980s (in some regions observed increases are substantially larger). The Met Office Hadley Centre has developed new techniques to update climatologies.

In many parts of the world there is the additional problem that observations are scarce. Improved monitoring is needed to address this in the future, but cannot fill in gaps in past data. Climate models such as PRECIS have been used to supplement incomplete climate records.

ASSESSING ENERGY REQUIREMENTS

The Met Office Hadley Centre was commissioned by the UK energy industry to investigate the potential impacts of climate change on a wide range of industry activities including generation, transmission and energy demand planning (EP2 Project). The energy industry has traditionally used historical data (mainly temperature) to estimate present-day energy demand and to plan for the next 10 years. Other industries use a similar approach: for example the construction industry uses historical climate data to help specify building regulations. Different averaging periods are used, and we have chosen the most recent 15 years as an example.

However, all historical averages are becoming increasingly unrepresentative of present-day climate. To generate improved climatologies, we used our decadal prediction system (DePreSys) to 'extend' the observed historical temperature record into the future for different regions of the UK. The long-term temperature average centred on the current year, or any year in the forthcoming decade, can then be calculated using a mix of observed and predicted temperatures.

The method has been tested for the UK from the mid-1980s. The benefits are clear. The 1961–1990 January temperature average underestimates present-day expectation for January temperature because climate change has already increased temperatures in the UK. Even the average over the most recent 15-year period underestimates the expectation for present-day temperatures, for the same reason.

The most accurate climatology is provided by constructing averages partly from historical data and partly from DePreSys predictions. Over all regions of the UK and all months of the year, the DePreSys-based predictions of climatology for the test period are at least 20% better than estimates using the 15-year observed averages, and at least 30% better than estimates using the 1961–1990 climatology.

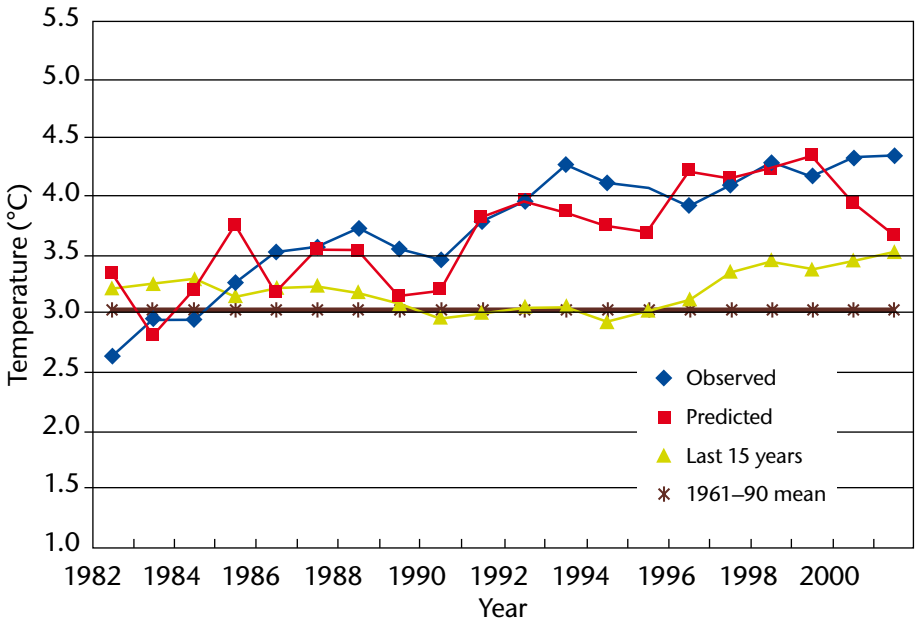


Figure 1. Observed and predicted January mean temperature climatology (estimated here by 13-year centred averages) for the Midlands (UK), centred on the year indicated, for the test period 1982–2002. The blue line shows the observed averages. The magenta line is the corresponding improved climatology derived by combining DePreSys predictions with observations (in this example data from ten predicted Januarys and three past observed Januarys are used). The yellow line uses the average observed temperature over the last available 15 Januarys to estimate present-day January climate. The brown line is the 1961–1990 climatological average.

Met Office
FitzRoy Road, Exeter
Devon, EX1 3PB
United Kingdom

Tel: 0870 900 0100
Fax: 0870 900 5050
enquiries@metoffice.gov.uk
www.metoffice.gov.uk

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Tools for adaptation and sustainable development – 2

Regional climate prediction (PRECIS) and longer-term water resources

REGIONAL CLIMATE PREDICTION (PRECIS)

Climate change will adversely affect developing countries whose economies are heavily dependent on agriculture and natural resources. It is vital these countries are able to make their own future predictions and combine them with local knowledge. The PRECIS (Providing Regional Climates for Impacts Studies) system was developed at the Met Office Hadley Centre to provide a tool for predictions. It is made widely available to developing countries as an adaptation tool. It has been used extensively to inform national communications to the UNFCCC[1] by a number of non-Annex 1 countries[2], enabling them to be more influential in the climate change debate.

Adaptation to change will require high quality climate change information, often with a lot of spatial detail. While global climate models are needed to understand and predict large-scale changes in climate they are not yet capable of providing the fine-scale information needed for some adaptation planning. This is because their horizontal resolution is too coarse to realistically include local climate forcings, such as mountains and inland water basins, or represent high-resolution climate phenomena such as fronts and cyclones. PRECIS generates high-resolution climate change information and can be applied in any region of the world.

[1] United Nations Framework Convention on Climate Change

[2] Mainly developing countries

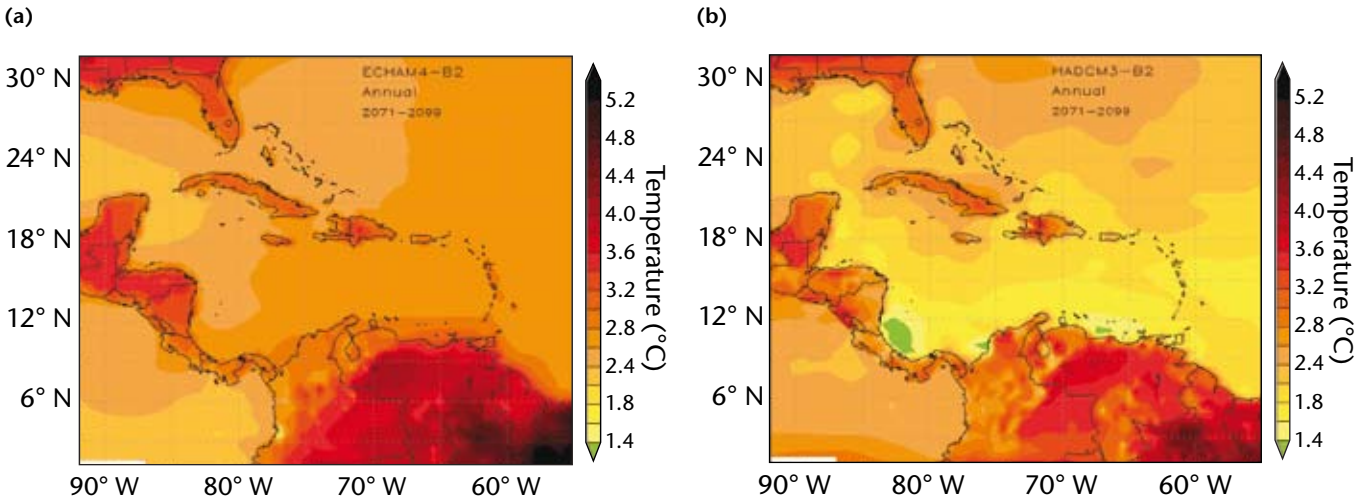

Figure 1. PRECIS projections of changes in near-surface temperature averaged over 2071–2099 compared to 1961–1990 for the SRES B2 IPCC emissions scenario using boundary conditions from: **(a)** the Max-Planck Institute GCM (ECHAM4), **(b)** the Met Office Hadley Centre GCM (HadCM3). (Centella A., A. Bezanilla and K. R. Leslie, 2008: A Study of the Uncertainty in Future Caribbean Climate Using the PRECIS Regional Climate Model, Caribbean Community Climate Change Center, Belmopan, Belize 15 pp)

Over the ocean and at the edges of the region covered it uses boundary conditions from global climate models. The system has recently been extended to enable users to explore the implications of uncertainties in the large-scale patterns of climate change. This is an important step in moving towards risk-based climate predictions.

Changes in rainfall and crop yield

One of the first applications of the assessment of uncertainty using PRECIS was in the Caribbean and Central America. PRECIS was run using boundary conditions from different global climate models. Sea-surface temperatures are determined by the global models and are very different. Land temperatures are generated by the regional model and are remarkably similar. In each case, annual average temperature increases of up to 4 °C by the end of the century are simulated over the land areas, even over the islands. A global model could not reproduce this, as it would not resolve the islands. The consistency of the land temperatures for the two projections gives extra agreement to the results. Given this level of agreement, it was reasonable to explore the potential impact on key crops for a wide a range of possible changes in rainfall. In all cases yield was predicted to decrease, whether rainfall increased or decreased.

"This project represents a joint effort in the region to provide the policy-makers with vital information. It is a fine example of the effectiveness of regional collaboration in helping us to meet global challenges such as those we may face with climate change. We, in the region, look forward to the further outputs from this commendable initiative and that no effort be spared, in ensuring the information is disseminated at all levels of the policy and decision-making in the Caribbean." [3]

The Hon. Said Musa
Prime Minister of Belize

Table. Simulated crop yields under current climate and with a 2 °C temperature increase accompanied by either a 20% increase or decrease in rainfall.

Crop	Temperature change (°C)	% change in precipitation	Yield (kg/ha)	Change in yield
Rice	0 +2 +2	0 +20 -20	3356 3014 2888	- -10% -14%
Beans	0 +2 +2	0 +20 -20	1354 1164 1093	- -14% -19%
Maize	0 +2 +2	0 +20 -20	4511 3737 3759	- -22% -17%

[3] From the foreword of Taylor, M.A., Centella, A., Charlery, J., Borrajero, I., Bezanilla, A., Campbell, J., Rivero, R., Stephenson, T.S., Whyte, F., Watson, R. (2007). Glimpses of the Future: A Briefing from the PRECIS Caribbean Climate Change Project, Caribbean Community Climate Change Centre, Belmopan, Belize 24 pp.

LONGER-TERM WATER RESOURCES

Many decisions about future investment in development and infrastructure require information on what our climate will be like in the next 10–20 years. This is most useful when considered alongside other factors such as population growth and technology changes. The Met Office Hadley Centre has pioneered a new system (known as DePreSys) to better predict the climate a decade ahead. Decadal models forecast natural climate variations, such as El Niño and fluctuations in the Gulf Stream, in addition to man-made climate change. Our technique has already been demonstrated to improve global mean temperature predictions. Climate forecasts on a regional basis are currently being assessed.

Such decadal forecasts are beginning to offer predictions of more direct relevance to organisations where adaptation to global warming is a key operational concern. In particular, they could prove strategically important for better development and infrastructure planning in many parts of the world. Our techniques will enable adaptation measures to be more precisely targeted to regions and times when they are most needed — saving lives and reducing costs.

Our forecasts can also help public and private sector decision-makers to deal with the threat from climate change by understanding its more immediate impacts on timescales that they will have to deal with in their working lifetime.

Precipitation changes by the 2030s
Decadal climate variability and climate change affect a number of key sectors such as public health and energy industries. In particular, changes in temperature and rainfall affect the prevalence and spread of certain diseases, as well as both demand and supply of electricity. DFID[4] and WHO[5] have commissioned the Met Office Hadley Centre to provide predictions of global changes in rainfall by the 2030s. The predictions are being used to assess the likely impact of climate change on the viability of current and planned technologies to provide water supply and sanitation consistent with targets set by the Millennium Development Goals. The final DFID/WHO report assessed the cost effectiveness and robustness of the technologies. It will be used to identify key research needs in terms of regions and technologies and to identify and promote technologies that are most appropriate in different regions.

[4] UK Department for International Development

[5] World Health Organization

Bangladesh in the 2020s and 2050s
While the southern part of Bangladesh suffers from frequent flooding due to storm surges, parts of the Ganges-Brahmaputra-Meghna Basin are likely to face increased water stress in the 2020s. The Met Office Hadley Centre, in collaboration with the CEH[6], produced water-stress assessments for Bangladesh[7]. Our results and their implications were discussed with stakeholders in Bangladesh in a workshop in Spring 2008 and will support improved decision-making. We are currently adding new capability to include the impact of melting mountain glaciers on future water resource assessments. Changes in the timing and amount of glacier melt might affect up to one-sixth of the world's population and be especially important in regions such as Bangladesh where the capacity to adapt is limited.

6 Centre for Ecology & Hydrology

7 F. Farquharson et al., 2007: Impact of climate and sea level change in part of the Indian subcontinent, CLASIC Final Report to Department for International Development, United Kingdom, KAR Project R8038, 125pp.

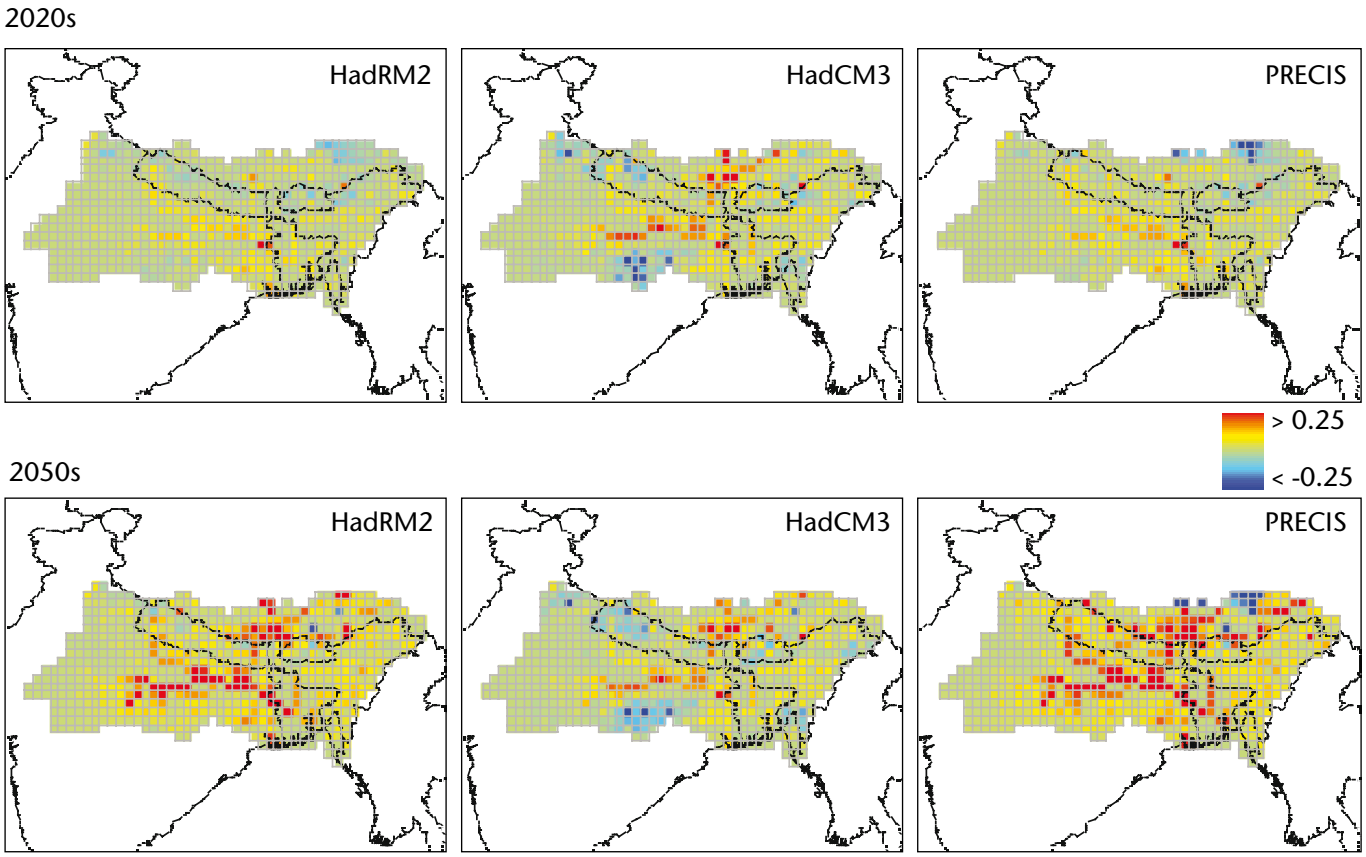

Figure 2. Changes in water availability index (derived from the CEH Global Water Availability Assessment (GWAVA) model) relative to present day, driven by three different Met Office Hadley Centre Climate models for 2020s and 2050s using a business as usual IPCC scenario. Positive values show increase in water stress. The different models give an estimate of the expected uncertainty.

Met Office
FitzRoy Road, Exeter
Devon, EX1 3PB
United Kingdom

Tel: 0870 900 0100
Fax: 0870 900 5050
enquiries@metoffice.gov.uk
www.metoffice.gov.uk

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The UK Climate Projections

Climate change is affecting our world now and, because of greenhouse gases already released, we are guaranteed further changes in the coming years and decades. While the extent of these changes will be influenced by the emissions we release today and in the future, any level of change will pose many potential threats and some possible opportunities. It is, therefore, essential to understand these issues so we can start adapting right away for the changes to come.

The UK Climate Projections 2009[1] are a major step forward in addressing this need for the UK. The Met Office Hadley Centre produced an ambitious and comprehensive analysis of regional climate change for UKCP09. The projections provide probabilistic information on how the UK's climate could change in the 21st century based on state-of-the-art climate models, observations and statistical analysis, combined with expert knowledge. The projections are a key part of a programme of decision support tools and measures from the UK Government to both encourage and support action to prepare for the impacts of our changing climate.

[1] UKCP09 — commissioned by the UK Government and Devolved Administrations. For more detail see website http://ukclimateprojections.defra.gov.uk The UK Climate Impacts Programme (UKCIP) provides the first point of contact to help stakeholders use UKCP09

HOW THE PROJECTIONS WERE MADE

UKCP09 is a major step forward from previous climate projections. Using the latest science and advanced computing power, they provide the most comprehensive information to date for the UK. They were produced using the Met Office Hadley Centre climate model and include the impact of changes in the carbon cycle which exacerbate climate change. There are still inherent uncertainties in producing projections, however. These focus on an incomplete understanding of the complex physical and biogeochemical processes of the atmosphere, ocean and land, combined with natural variability. There is also uncertainty as to how man-made greenhouse gas emissions will change over the projection period.

UKCP09 tackles these uncertainties by using a range of projections generated by running the climate model several hundred times using a range of different values for key parameters. This means many nuances in the understanding of atmospheric science are taken into account. To ensure an even wider spread of the possibilities is considered, data from 12 of the world's other leading models have also been incorporated into the projections. For the more local projections (at 25km resolution), more detailed climate models were run to include local factors that are known to affect regional climate, such as mountains and coastline. The projections don't quantify all sources of uncertainty (for example errors common to all climate models), but they make an important first step.

Levels of confidence in each of the projections have been included. It is important to realise that the probabilities depend on the weight of current evidence, including expert opinion. As our knowledge of the science is improved and incorporated into future climate models, the probabilistic projections will need to be refined. Hence, the probabilities reflect how confident we are that a change will happen, not the 'percentage chance' of it occurring. As a snapshot, the 50 per cent probability level (where the evidence for being above or below this level is equally strong) gives a useful central estimate or average projection. Looking at the spread of projections at different probabilities will give a clearer picture, however, and is essential for risk management.

The probabilistic approach, used at a regional level for the first time, allows UKCP09 users to get a clear picture of the probability attached to each projection within a range. This enables an informed approach to risk — a highly important assessment when making vital decisions on levels of adaptation.

HOW THE PROJECTIONS ARE DELIVERED

Probabilistic projections are given at a resolution of 25 km, but are also presented as averages over larger land and marine regions. They are delivered over seven overlapping 30-year periods and for three future greenhouse gas emissions scenarios[2]. Variables covered include temperature, precipitation, relative humidity, cloud cover, heat radiation and mean sea-level pressure. Monthly, seasonal and annual averaged data are also provided.

EXPECTED CHANGES IN CLIMATE

The medium emissions scenario constitutes a world where the economy and population continue to grow, but we move away from fossil fuels to a more balanced energy mix and adopt new energy saving technologies. Under such a scenario, temperatures will increase across the UK more in summer than in winter.

By the 2080s, the average maximum temperature increase of a summer's day in South East England is likely to be above 2 °C and below 9 °C[3]. The central

[2] The IPCC SRES A1FI (called high in UKCP09), A1B (medium) and B1 (low).

[3] Temperature changes are relative to a 1961–1990 average baseline. The range given is from the 10% probability level to the 90% probability level.

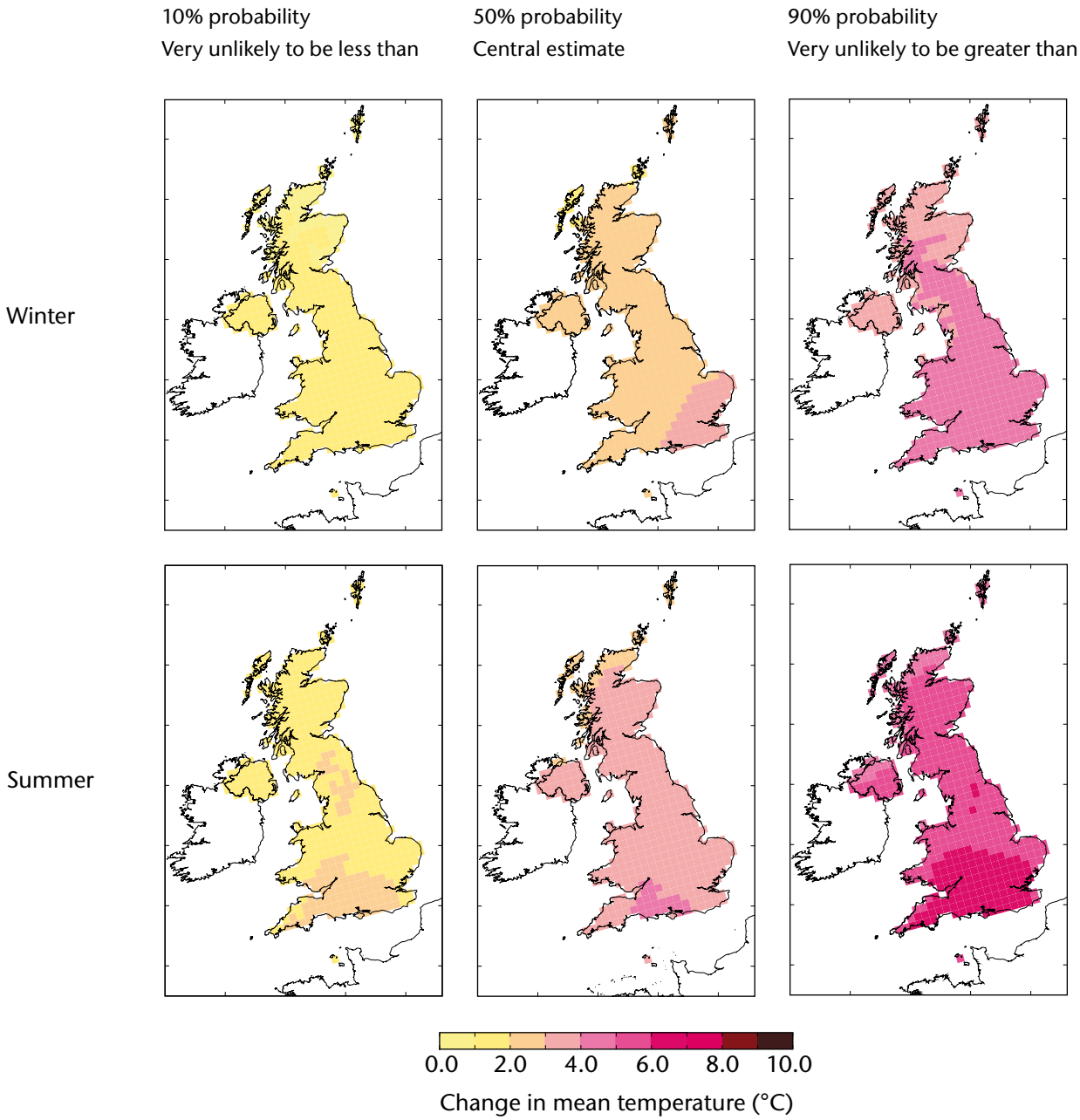

Figure 1. Maps of winter and summer temperature change for 2070–2099 using a medium emissions scenario compared with 1961–90.

estimate is 5.5 °C. The impacts on the warmest day of summer could be even more dramatic. Although the central estimate of increases in the warmest day is only 3 °C for the south-east, the range is bigger than for average temperature. So there is a 10% probability that increases could be 10 °C or more in some parts of the UK. In a high emissions scenario, it is possible temperatures in London could reach a peak of 41 °C in a typical summer, warmer than the current UK record temperature of 38.5 °C recorded on 10 August 2003 in Faversham, Kent.

If we look only 40 years ahead to the 2050s we can still expect dramatic changes in climate, regardless of what we do to decrease emissions in the interim. We are locked in a climate trajectory for the next 30 years that reflects our historic emissions. So under all scenarios, central estimates of average summer daily maximum temperature increases are between 3.5–4.5 °C leading to temperatures of 23.5–24.5 °C, making a typical summer as hot as the current warmest years on record. The 2003 and 2006 summer daily maximum temperatures were 23 °C and even the record-breaking summer of 1976 only reached an average of 24.1 °C.

All areas will see increased winter rainfall (for example, by the 2080s increases are very likely to be no more than 34% in North West England under a medium emissions scenario) and decreased summer rainfall (decreases are very likely to be no more than 48% in South East England under a medium emissions scenario), with little overall change in the annual average.

MARINE PROJECTIONS

There is growing evidence that climate change is already affecting the marine environment in a number of ways and more changes are expected in the future. These changes will affect issues such as coastal flooding, habitat conservation and food security. To adapt to these threats and plan for the risks, it is increasingly important to have good estimates of what could happen in the marine environment. UKCP09 provides marine projections for the seas around the UK based on a number of scenarios to enable users to assess how vulnerable particular sites or sectors are to climate change.

The UKCP09 marine scenarios provide the most up to date and comprehensive set of marine climate projections. Focus extends outwards from the coastal zone and into the waters of the shelf-seas around the UK. For the first time consistent scenarios are included of changes in sea-level rise, storm surges, shelf-sea temperature, salinity, circulation and waves. This will enable credible comparisons of marine climate changes across a range of sectors.

Where appropriate, uncertainty ranges are estimated. For sea-level rise and storm surge two ranges are provided: the uncertainty estimated from current climate models and a wider uncertainty range, called High++, which presents a plausible upper estimate of sea-level rise and storm surge, but is considered a highly unlikely and extreme scenario.

Key findings

- Projected likely absolute UK coastal sea-level rise for 2095 ranges from 12–76cm. The local sea-level rise will be a combination of this absolute value and local vertical movement of the land.
- Extreme water levels will also increase, as shown in Figure 2 (a). However, these changes are likely to be small. They are driven more by changes in mean sea-level than changes in atmospheric storms.
- Under the very unlikely High++ scenario, the water level of a one-in-50-year extreme event could increase by as much as 3m in some places over the 21st century, shown in Figure 2 (b).
- Seasonal average wave height and extreme waves are expected to increase slightly in the South West of the UK and reduce slightly in the North. There is less confidence in projections for waves, however, than for sea-level rise and storm surge.
- In the open ocean, shelf-edge regions and northern parts of the North Sea, temperature increases over the 21st century of around 1.5 to 2.5 °C are projected. Larger increases of around 2.5–4 °C are projected for the Celtic, Irish, and southern North Sea.
- The seas around the UK are projected to become fresher (less salty) by the end of the 21st century.

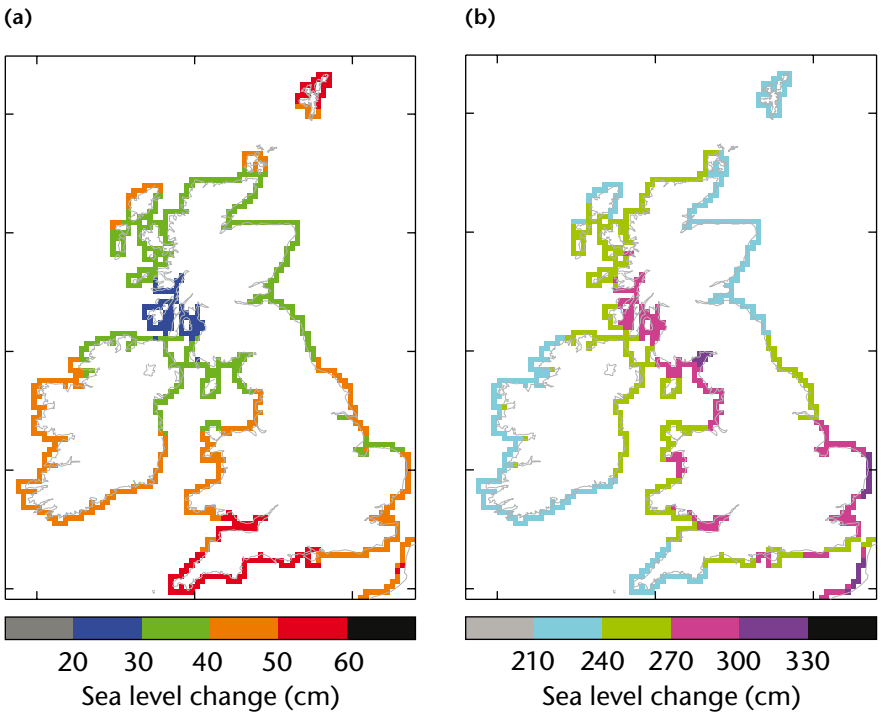

Figure 2. (a) Central estimate of 21st century change in extreme sea-level with a 50-year return period. **(b)** Upper limit of the "High ++" 21st century change in extreme sea-level with a 50-year return period.

Met Office
FitzRoy Road, Exeter
Devon, EX1 3PB
United Kingdom

Tel: 0870 900 0100
Fax: 0870 900 5050
enquiries@metoffice.gov.uk
www.metoffice.gov.uk

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A project commissioned by the
Association of British Insurers

The financial risks of climate change

Warming temperatures are expected to influence the pattern and intensity of rainfall, winds and storms in the future. This means the amount of inland flooding and storm damage, as well as its geographic spread, is likely to change. This is a major consideration for insurance companies providing cover for weather-related losses. Understanding how future claim levels may change is essential for the insurance industry to ensure premiums are set at the right level and there is enough capital to cover potential claims. While there is considerable uncertainty over the exact extent of changes in our climate, the industry nevertheless must assess the potential impacts to allow a controlled approach to risk.

The Association of British Insurers asked catastrophe modelling experts, AIR Worldwide, to conduct a study with the Met Office to assess the financial impacts of climate change. The study focuses on the dominant natural hazards in the UK, including wind and inland flooding damage, and typhoon damage in China.

FINANCIAL IMPACTS FROM CLIMATE SCIENCE AND CATASTROPHE MODELS

The Met Office created a series of climate scenarios using output from state-of-the-art climate models, as well as a diverse range of published scientific research and data. The scenarios were then used by AIR Worldwide to adjust their catastrophe models, providing a unique insight into relationships between climate change and potential financial risk impacts.

The Met Office Hadley Centre also provided updates to key science questions on important related issues such as:

- What are the likely timescales of reaching 2 °C and 4 °C of global warming if emissions continue on business as usual or are reduced through international agreement?
- How have projections of sea-level rise been updated since the IPCC 4th assessment report was released?
- How robust and dependable are climate data — globally and for the UK and China?

Results included three key measures for the insurance industry:

i) Average annual loss (AAL), reflecting the expected amount of insured loss per year over a long-term period.

ii) 100-year-loss (average loss from a 1-in-100-year weather event).

iii) 200-year-loss (average loss from a 1-in-200-year weather event).

KEY FINDINGS

For both the UK and China there was a strong relationship between increasing global temperatures and rainfall, but no clear dependence between global temperatures and windstorms or typhoons. As a result, the study focused on scenarios of variations in position of the storm track for changes to future windstorm, and illustrative scenarios of changes in typhoon intensity.

Significant increases in insured risk can be expected across all the key measures. Key results, excluding GDP growth, include:

- Average annual insured flood losses for Great Britain could rise by 14% to £633 million (valid for a global temperature rise of 4 °C).
- Average annual insured wind losses for the UK could rise by 25% to £827 million (valid for slight southward shift in storm track).
- Insured flood losses occurring on average once every 100 years in Great Britain could rise by 30% to £5.4 billion, and flood losses occurring on average once every 200 years could rise by 32% to £7.9 billion (valid for a global temperature rise of 4 °C).
- Insured wind-related losses from winter season windstorms in the UK occurring on average once every 100 years could rise by 14% to £7.3 billion, and losses occurring once every 200 years could rise by 12% to £9.7 billion (valid for a slightly southward shift in storm track).
- Average annual insured losses from typhoons affecting China could increase significantly by 32% to £345 million; a 1-in-100 year loss in China could increase to £838 million; and a 1-in-200 year loss in China could reach £1.1 billion (valid for a global temperature rise of 4 °C).

IMPACTS FOR THE INSURANCE INDUSTRY

The impacts of these forecasts on both the level of premiums charged and level of capital required by insurance companies was also considerable. For example, for a global 4 °C temperature rise, insured flood losses in Great Britain could lead to insurance rate increases of 21% and a further £1.9 billion could be added to the £5.9 billion capital requirement.

By combining expert knowledge in the fields of climate and actuarial science, this report provides a detailed analysis relating climate change to its potential impact on insurers. There are a number of variables involved in the research, however, which means there are inevitably limitations to the information provided. Some risks, such as sea-level rise, were not included in the financial analysis. When combined with other tools for analysing and managing risk, this study provides a cutting-edge approach which can be updated as models improve. A clearer picture of how society responds to the challenges of climate change through emissions reduction and adaptation measures will also provide more certainty in loss projections.

ABI Association of British Insurers

AIR WORLDWIDE

Met Office
FitzRoy Road, Exeter
Devon, EX1 3PB
United Kingdom

Tel: 0870 900 0100
Fax: 0870 900 5050
enquiries@metoffice.gov.uk
www.metoffice.gov.uk

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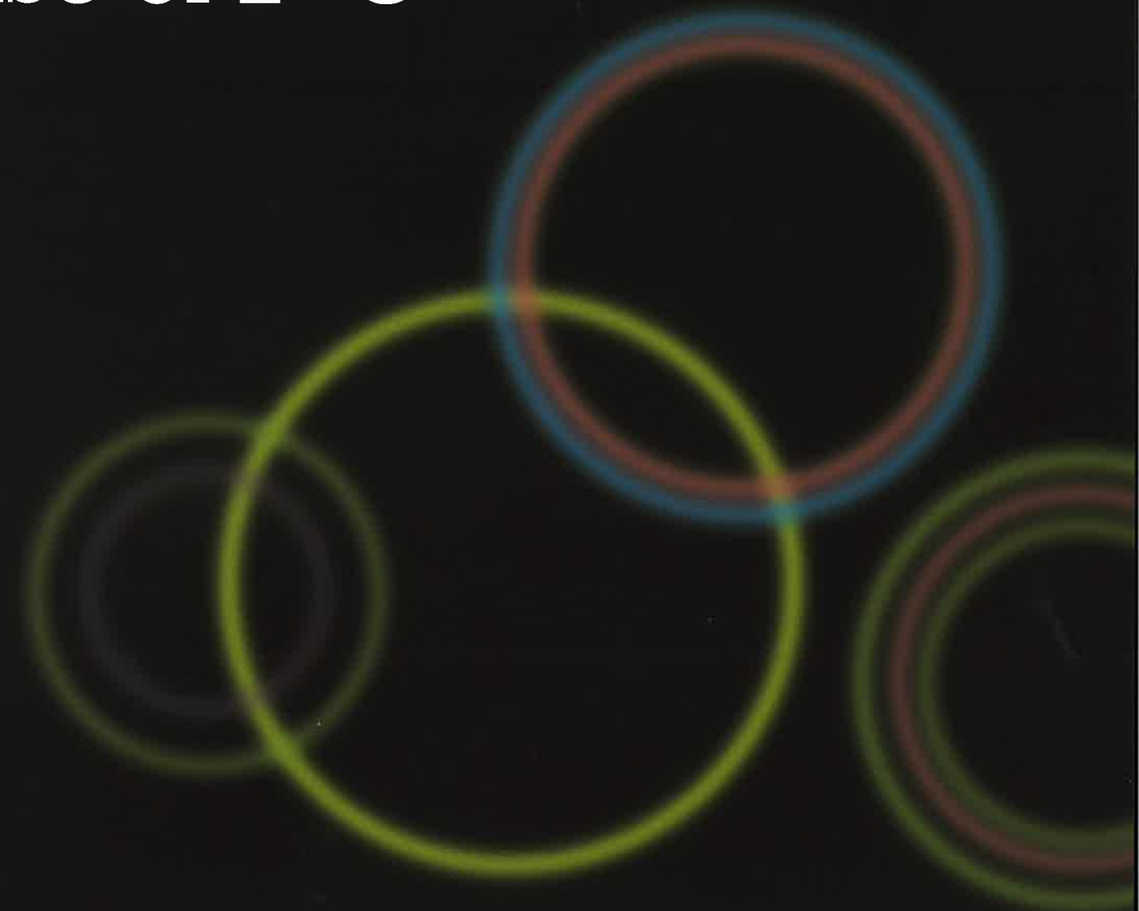
Met Office
Hadley Centre

The impact of a global temperature rise of 2 °C



This poster highlights some of the impacts that may occur if the global average temperature rises by 2 °C above the pre-industrial average climate.

This projection was generated using the Met Office Hadley Centre's HadCM3 model and shows that an average rise of 2 °C will not be spread uniformly across the globe. To create the map, the model was run many times for two different greenhouse gas emission scenarios. These are two of the socio-economic scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), representing greenhouse gas emissions (and other emissions such as aerosols) for future development. The two used here are known as A1B and A1FI.

The output of each of these simulations (34 in total) was averaged for the decade when they crossed the 2 °C threshold. This is the projection shown. This projection does not therefore include information about timescales of climate change or the likelihood of reaching 2 °C.

For most of the impacts shown here, the date by which the global average temperature rises to 2 °C above the pre-industrial average is not significant. However, it is important for sea-level rise, and for this issue only we have assumed a 2 °C increase by the end of the century.

The impacts shown on the map are only a selection of those that may occur and are focused primarily on the effect of climate change on human activity.

The evidence for the impacts shown comes from a number of different research studies. In some cases the impacts have been driven by different model projections, although the climate data used is consistent with a 2 °C global average-temperature rise.

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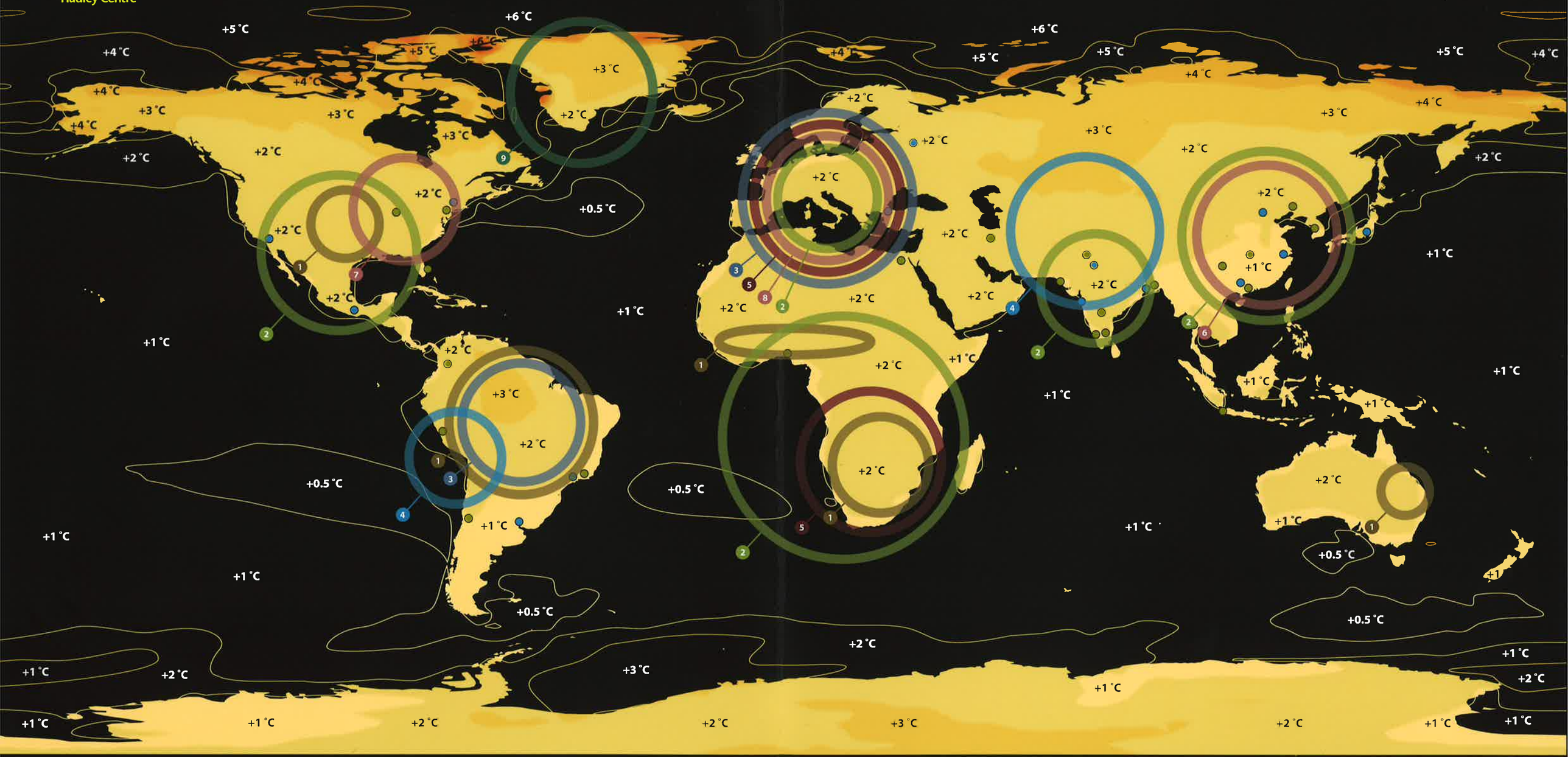
Met Office
Hadley Centre

The impact of a global temperature rise of 2 °C



This poster highlights some of the impacts of a global average-temperature rise of 2 °C above the pre-industrial average climate. This compares with the equivalent impacts for a global average-temperature rise of 4 °C, which are far more severe and widespread.

1. High forest-fire danger is projected to become more widespread as temperatures rise. Regions moving into the high-danger category include some areas of South America, along with small areas of the US, southern and east Africa, the Sahel and eastern Australia.

2. Production of some cereal crops may increase at mid- to high-latitudes due to rising temperatures and longer growing seasons. However, in semi-arid and tropical regions the impacts of warming will frequently be more negative, especially in regions where farming is already marginal.

3. Rising temperatures will cause changes in rainfall patterns and increase evaporation. This will affect river flows and the availability of water, with some populations experiencing an increase in water resource and others experiencing a decrease.

4. Glacier melt is an important source of fresh water for many communities. Rising temperatures mean that glacier melt will continue and the extent of melting will be greater in some regions than others. Although in the short term this will increase water availability, in the longer term this threatens the sustainability of water supplies.

5. Drought events occur one-and-a-half times as frequently across southern Africa and the Mediterranean basin.

6. Hottest days of the year could be as much as 4 °C warmer in highly populated areas of eastern China. A global average-temperature rise of 4 °C would result in hottest days being 6 °C warmer for the same region.

7. Hottest days of the year could be as much as 8 °C warmer over eastern North America, affecting Toronto, Ottawa, New York and Washington DC. A global average-temperature rise of 4 °C would result in hottest days being 10-12 °C warmer for the same region.

8. Hottest days of the year across Europe could be as much as 6 °C warmer. A global average-temperature rise of 4 °C would result in hottest days being 8 °C warmer for the same region.

9. Global average sea-level rises by up to approximately 40 cm by the end of the century. The long-term contribution from melting ice sheets could be larger still.

+ °Celsius — Change in temperature from pre-industrial climate

0	1	2	3	4	5	6	7	8	9
0	2	4	5	7	9	11	13	14	16

+ °Fahrenheit

City populations
- 5 - 10 Million
- 10 - 20 Million

Source: UN Statistics Division Demographic Yearbook 2007

These impacts make no assumptions about adaptive capacity

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QUEST Quantifying and Understanding the Earth System

Walker INSTITUTE

Tyndall Centre for Climate Change Research

University of Southampton

PIK

National Oceanography Centre, Southampton
University of Southampton and Natural Environment Research Council

The impact of a global temperature rise of 4 °C (7 °F)

"If we allow the global average temperature to rise by 4 °C then the science tells us that we can expect severe and widespread impacts worldwide. We can take action now to prevent that temperature rise and avoid those global impacts."

Dr Richard Betts, Head of Climate Impacts, Met Office Hadley Centre

This poster highlights some of the impacts that may occur if the global average-temperature rises by 4 °C (7 °F) above the pre-industrial climate average.

This projection was generated using Met Office Hadley Centre's HadCM3 model, and shows that an average rise of 4 °C (7 °F) will not be spread uniformly across the globe. To create the map the model was run many times, for two different greenhouse gas emission scenarios. These are two of the socio-economic scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), representing greenhouse gas emissions (and other emissions such as aerosols) for future development without active mitigation against climate change. The two used here are known as A1B and A1FI. Out of a total of 34 model runs, 23 runs showed the global average temperature rising above 4 °C (7 °F) by the end of the century. Emissions are currently running close to the A1FI scenario and for this scenario all but one the model runs reached a 4 °C (7 °F) global average temperature rise in this time. The range was 3.2 °C (5.8 °F) to 6.7 °C (12.1 °F). The output of each of these 23 simulations was averaged for the decade when they crossed the 4 °C (7 °F) threshold. This is the projection shown. This projection does not therefore include information about timescales of climate change or the likelihood of reaching 4 °C (7 °F).

The impacts shown on the map are only a selection of those that may occur and are focused primarily on the effect of climate change on human activity. Where numbers of people are quoted, the underlying assumption is that population changes will follow the population projections used by the IPCC to develop the A1B emission scenario. This means that the impacts are consistent with each other.

However, the evidence for the impacts shown comes from a number of different research studies. In some cases the impacts have been driven by different model projections, although all the climate data used is consistent with a 4 °C (7 °F) global average-temperature rise.

Adaptation options to the impacts shown on the map may or may not always be feasible. For this reason no assumptions are made about the adaptive capacity of the countries and regions affected. Instead, the values described as 'up to' indicate the worst case in a range of outcomes that include model uncertainty and behavioural responses.

Contributors

Met Office Hadley Centre

Dr Richard Betts, Dr Ben Booth, Dr Eleanor Burke, Dr Robin Clark, Dr Rutger Dankers, Dr Jemma Gornall, Dr Maggie Hendry, Dr Debbie Hemming, Dr Tom Howard, Dr Gillian Kay, Kirsty Lewis, Dr Jason Lowe, Dr Mark McCarthy, Dr Jeff Ridley, Dr Michael Sanderson, Dr Ian Totterdell, Dr Kate Willett, Dr Claire Witham

National Oceanography Centre, Southampton

Dr Toby Tyrrell

Potsdam Institute for Climate Impacts Research

Dr Jochen Hinkel

Tyndall Centre

University of Southampton, Centre for Coastal Processes, Engineering and Management, School of Civil Engineering and Environment

Prof. Robert Nicholls, Dr Sally Brown

Walker Institute for Climate System Research, University of Reading

Prof. Nigel Arnell, Dr Tom Osborne, Prof. Tim Wheeler

Reviewers

Dr Mark New, University of Oxford and Tyndall Centre

Prof. Martin Parry, Grantham Institute and Centre for Environmental Policy, Imperial College, London

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The impact of a global temperature rise of 4 °C (7 °F)

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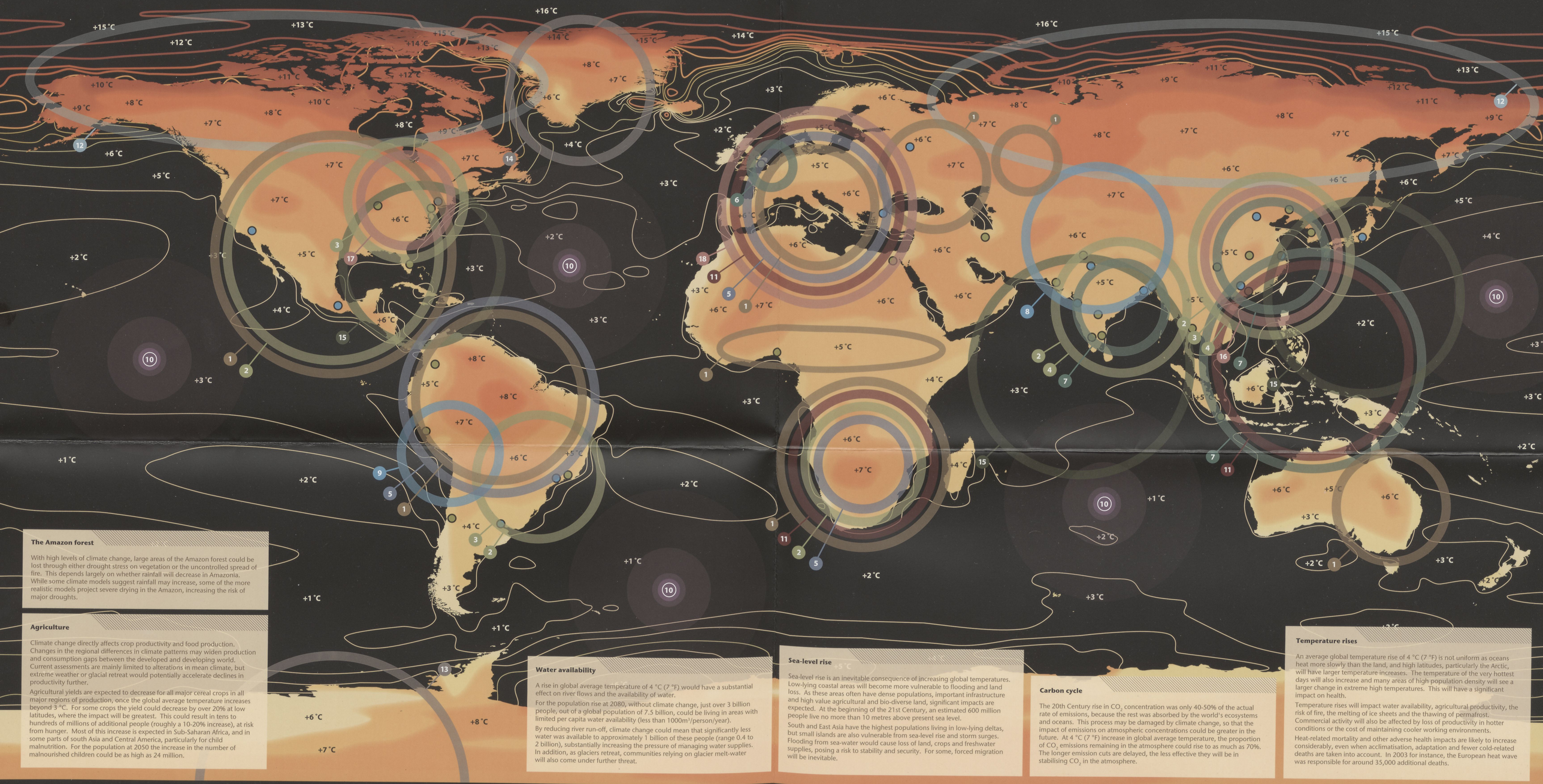

The Amazon forest

With high levels of climate change, large areas of the Amazon forest could be lost through either drought stress on vegetation or the uncontrolled spread of fire. This depends largely on whether rainfall will decrease in Amazonia. While some climate models suggest rainfall may increase, some of the more realistic models project severe drying in the Amazon, increasing the risk of major droughts.

Agriculture

Climate change directly affects crop productivity and food production. Changes in the regional differences in climate patterns may widen production and consumption gaps between the developed and developing world. Current assessments are mainly limited to alterations in mean climate, but extreme weather or glacial retreat would potentially accelerate declines in productivity further.

Agricultural yields are expected to decrease for all major cereal crops in all major regions of production, once the global average temperature increases beyond 3 °C. For some crops the yield could decrease by over 20% at low latitudes, where the impact will be greatest. This could result in tens to hundreds of millions of additional people (roughly a 10-20% increase), at risk from hunger. Most of this increase is expected in Sub-Saharan Africa, and in some parts of south Asia and Central America, particularly for child malnutrition. For the population at 2050 the increase in the number of malnourished children could be as high as 24 million.

Water availability

A rise in global average temperature of 4 °C (7 °F) would have a substantial effect on river flows and the availability of water.

For the population rise at 2080, without climate change, just over 3 billion people, out of a global population of 7.5 billion, could be living in areas with limited per capita water availability (less than 1000m³/person/year).

By reducing river run-off, climate change could mean that significantly less water was available to approximately 1 billion of these people (range 0.4 to 2 billion), substantially increasing the pressure of managing water supplies. In addition, as glaciers retreat, communities relying on glacier melt-water will also come under further threat.

Sea-level rise

Sea-level rise is an inevitable consequence of increasing global temperatures. Low-lying coastal areas will become more vulnerable to flooding and land loss. As these areas often have dense populations, important infrastructure and high value agricultural and bio-diverse land, significant impacts are expected. At the beginning of the 21st Century, an estimated 600 million people live no more than 10 metres above present sea level.

South and East Asia have the highest populations living in low-lying deltas, but small islands are also vulnerable from sea-level rise and storm surges. Flooding from sea-water would cause loss of land, crops and freshwater supplies, posing a risk to stability and security. For some, forced migration will be inevitable.

Carbon cycle

The 20th Century rise in CO_2 concentration was only 40-50% of the actual rate of emissions, because the rest was absorbed by the world's ecosystems and oceans. This process may be damaged by climate change, so that the impact of emissions on atmospheric concentrations could be greater in the future. At 4 °C (7 °F) increase in global average temperature, the proportion of CO_2 emissions remaining in the atmosphere could rise to as much as 70%. The longer emission cuts are delayed, the less effective they will be in stabilising CO_2 in the atmosphere.

Temperature rises

An average global temperature rise of 4 °C (7 °F) is not uniform as oceans heat more slowly than the land, and high latitudes, particularly the Arctic, will have larger temperature increases. The temperature of the very hottest days will also increase and many areas of high population density will see a larger change in extreme high temperatures. This will have a significant impact on health.

Temperature rises will impact water availability, agricultural productivity, the risk of fire, the melting of ice sheets and the thawing of permafrost. Commercial activity will also be affected by loss of productivity in hotter conditions or the cost of maintaining cooler working environments.

Heat-related mortality and other adverse health impacts are likely to increase considerably, even when acclimatisation, adaptation and fewer cold-related deaths are taken into account. In 2003 for instance, the European heat wave was responsible for around 35,000 additional deaths.

1. High forest-fire danger projected to affect every populated continent. Regions moving into the high-danger category include: large areas of the United States; Mexico; South America, east of the Andes; southern and east Africa; the Sahel; eastern and southern Australia and southern Europe.
2. Maize and wheat yields reduced by up to 40% at low latitudes.
3. Soybean yield could decrease in all regions of production, including North and South America, southern and eastern Asia.
4. Decrease in rice yield of up to 30% in China, India, Bangladesh and Indonesia.
5. Water resources affected by up to 70% reduction in run-off around the Mediterranean, southern Africa and large areas of South America.
6. Sea-level rise combined with storm surges could pose a serious threat to people and assets in the Netherlands and south-eastern parts of the UK.
7. Sea levels could rise as much as 80 cm by the end of the century. Longer term, 4 °C (7 °F) would result in a much higher rise in sea level.
   Sea level increases are likely to be even greater at low latitudes, disproportionately affecting tropical islands and low-lying regions such as Bangladesh.
   For the population at 2075, a mean sea-level rise of 53 cm means that up to an additional 150 million people per year would be flooded due to extreme sea levels. Three-quarters of these people live in Asia. Up to 56 million people would be flooded along the Indian Ocean coast, 25 million along the east Asian coast and 33 million people would be flooded along the South-East Asian coast.
   Other vulnerable regions include Africa, Caribbean islands, Indian Ocean islands and Pacific small islands.
8. Half of all Himalayan glaciers significantly reduced by 2050, even at a global average temperature rise below 4 °C.
   The Indus river basin obtains 70% of its summer flow from glacial melt.
   In China, 23% of the population lives in the western regions where glacial melt provides the principal dry season water source.
9. Complete disappearance of glaciers from many regions in South America.
   In Peru's Cordillera Blanca summer run-off from glaciers reduced by up to 69% as the glacial area falls by 75%.
10. Marine ecosystems could be fundamentally altered by ocean acidification which would have a significant impact on fisheries. This could cause substantial loss in revenue and jobs. The loss of coral reef habitats due to acidification may seriously affect many commercial fish species and could prove disastrous for coastal communities relying on subsistence fishing of reef species.
11. Drought events occur twice as frequently across southern Africa, South-East Asia and the Mediterranean basin.
12. Almost complete disappearance of near-surface permafrost from Northern Siberia. Reduction of permafrost in Canada and Alaska. Infrastructure built on the permafrost foundation at risk.
13. It is not known how stable the West Antarctic Ice Sheet is, or whether a 4 °C (7 °F) global temperature rise will send it into irreversible decline. If this ice sheet did melt it would contribute a further 3.3 metres to long-term sea-level rise globally.
14. Greenland Ice Sheet has a 60% likelihood of irreversible decline. This would result in a very long-term sea-level rise of up to 7 metres globally.
15. Tropical cyclones could be more intense and destructive. Global population increases, particularly in coastal areas, and sea-level rise mean greater cyclone and hurricane related losses, disruptions to infrastructure and loss of life as a result of storm surges. For major cyclone disasters flooding from storm surges has been the primary cause of death.
16. Hottest days of the year could be as much as 6 °C (11 °F) warmer over highly populated areas of eastern China.
17. Hottest days of the year could become as much as 10-12 °C (18-22 °F) warmer over eastern North America, affecting Toronto, Chicago, Ottawa, New York and Washington DC.
18. Hottest days of the year across Europe could be as much as 8 °C (14 °F) warmer.

Disease patterns have changed with an overall increase in diarrhoea, vector-borne disease such as malaria and dengue fever, malnutrition and the health impacts of weather events such as flooding and drought.

Change in temperature from pre-industrial climate

+°Celsius	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
+°Fahrenheit	2	4	5	7	9	11	13	14	16	18	20	22	23	25	27	29

City populations: 5 - 10 Million; 10 - 20 Million

Source: UN Statistics Division Demographic Yearbook 2007

These impacts make no assumptions about adaptive capacity. For further information about this map go to: http://www.metoffice.gov.uk/climatechange/guide/effects/

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